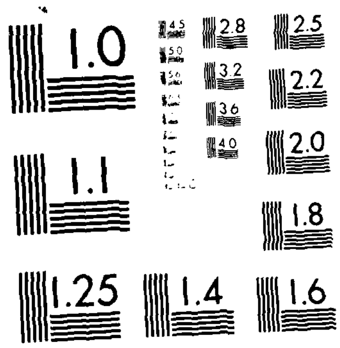
AD-A163 075 PRODUCTION AND CONTROL OF ION CYCLOTRON INSTABILITIES IN THE HIGH LATITUD. (U) NAVAL RESEARCH LAB WASHINGTON DC P K CHATURVEDI ET AL. 30 DEC 85 NRL-MR-5667 1/1

UNCLASSIFIED F/G 4/1 NL

END
FILMED
DTIC


1.0
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

(2)

NRL Memorandum Report 5667

Production and Control of Ion Cyclotron Instabilities in the High Latitude Ionosphere by High Power Radio Waves

P. K. CHATURVEDI AND M. J. KESKINEN

Geophysical and Plasma Dynamics Branch
Plasma Physics Division

S. L. OSSAKOW

Plasma Physics Division

December 30, 1985

This work was supported by the Office of Naval Research.

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS: AD-A163075

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5667

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory

6b OFFICE SYMBOL (If applicable): Code 4780

7a NAME OF MONITORING ORGANIZATION:

6c ADDRESS (City, State, and ZIP Code): Washington, DC 20375-5000

7b ADDRESS (City, State, and ZIP Code):

8a NAME OF FUNDING / SPONSORING ORGANIZATION: Office of Naval Research

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code): Arlington, VA 22217

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61153N	RR033-02-44		DN880-024

11 TITLE (Include Security Classification): Production and Control of Ion Cyclotron Instabilities in the High Latitude Ionosphere by High Power Radio Waves

12 PERSONAL AUTHOR(S): Chaturvedi, P.K., Keskinen, M.J. and Ossakow, S.L.

13a TYPE OF REPORT: Interim

13b TIME COVERED: FROM ______ TO ______

14 DATE OF REPORT (Year, Month, Day): 1985 December 30

15 PAGE COUNT: 23

16 SUPPLEMENTARY NOTATION: This work was supported by the Office of Naval Research.

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Ionospheric heating; Ionospheric irregularities; Ion cyclotron instability; High latitude ionosphere

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The possible generation and suppression of ion cyclotron waves in a collisional plasma by external high power electromagnetic (EM) waves with frequency close to the local upper-hybrid frequency is considered. It is shown that the ion cyclotron instability can be destabilized (stabilized) for $\omega_o < \omega_{UH}$ ($\omega_o > \omega_{UH}$), where ω_o is the pump frequency of the EM wave. The results are applied to naturally occurring ion cyclotron instabilities in the high latitude ionosphere.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL: J. D. Huba

22b TELEPHONE (Include Area Code): (202) 767-3630

22c OFFICE SYMBOL: Code 4780

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

PRODUCTION AND CONTROL OF ION CYCLOTRON INSTABILITIES IN THE HIGH LATITUDE IONOSPHERE BY HIGH POWER RADIO WAVES

I. INTRODUCTION

It is now recognized that many of the phenomena occurring in the auroral ionosphere may be associated with the presence of the field-aligned current-systems which are a constant feature at these latitudes [see e.g., Burke, 1981]. In addition to being a key component of the ionosphere-magnetosphere coupling circuit, these currents may also be responsible in generating micro-and/or macro-structures (turbulence) in the ambient plasmas at low altitudes. Such structures have been observed by various measurement techniques (ground based ionosonde, VHF radar backscatter, optical measurements, scintillations, in-situ rocket and satellite measurements, etc.) A catalogue of the structure scale sizes spans the domain from a few meters to a few hundreds of kilometers [see e.g., Aarons, 1973; Clark and Raitt, 1976; Dyson, 1969; Dyson and Winningham, 1974; Fremouw et al., 1977; Greenwald, 1974; Hanuise et al., 1981; Hower et al., 1966; Kelley et al., 1980; Ogawa et al., 1976; Olesen et al., 1976; Phelps and Sagalyn, 1976; Sagalyn et al., 1974; Vickrey et al., 1980; Weaver, 1965]. Recent theoretical studies have attempted to interpret these structures in terms of plasma instabilities, neutral turbulence, structured particle precipitation, convection flows, etc. [Keskinen and Ossakow, 1983]. Due to the ever-varying conditions prevalent in the auroral ionosphere, it seems likely that all of these processes may be occuring at one time or another. In some instances, different processes can result in similar observable effects which makes the resolution of individual mechanisms difficult and introduces complications in the modelling process. The use of active experiments in the near-earth space offers an

Manuscript approved July 29, 1985.

attractive complement to the studies of understanding of natural plasma processes occurring in the ionosphere. One technique that has been widely used is the modification of the ionosphere using powerful radio waves [Utlaut, 1970; Fialer, 1974; Thide et al., 1982; Stubbe et al., 1981; Wong et al., 1981] A considerable amount of theoretical work has been done in this field [Perkins and Kaw, 1971; Perkins et al., 1974; Fejer, 1979; Vaskov and Gurevich, 1977; Das and Fejer, 1979; Stenflo, 1983]. One of the possible consequences of the interaction of a large amplitude EM wave with the ionosphere is the generation of structures in the ambient plasma density. This may come about several ways; one of them being the excitation of plasma instabilities by an electromagnetic pump wave under sub-threshold conditions. By the same token, one could use the same principle of parametric coupling of the external pump and the natural plasma modes to suppress a current-driven or gradient-driven plasma instability in the system. Work on basic parametric instability processes in plasmas is exhaustive [Silin, 1965; DuBois and Goldman, 1965; Nishikawa, 1968]. The application of these ideas to the possible control of ionospheric irregularities was originally made by Lee et al. [1972] for the case of equatorial electrojet; and, has since been applied for the equatorial spread F situation [Bujarbarua and Sen, 1978] and the auroral ionosphere [Keskinen et al., 1983]. In this report, we examine the possibility of external control (excitation or suppression) of the current-driven ion-cyclotron instability in the auroral ionosphere. In addition to being excited in the topside ionosphere [Kindel and Kennel, 1971], the current-driven ion cyclotron instability may also be triggered in the collisional bottomside ionosphere [Chaturvedi, 1976; Satyanarayana et al., 1985; Fejer et al., 1984] by a radio-wave at the local upper-hybrid frequency. In the next section, we outline the theory, and, estimate the

incident power density required to stabilize or destabilize the instability. The final section considers application of these results to the bottomside high latitude F region ionosphere.

II. THEORY

We follow the theoretical procedure outlined in Lee et al. [1972] and Keskinen et al. [1983] for the calculation of the dynamic plasma response to a large amplitude electromagnetic pump wave. The equilibrium consists of a field-aligned current $J_0\hat{\underline{z}}(= - n_0 e V_0 \hat{\underline{z}})$ and an oscillating electric field $\underline{E}_0 = \underline{E}_p \cos \omega_0 t$. We have equated the zero-order current to an equilibrium electron drift $V_0\hat{\underline{z}}$ and have used the so-called dipole approximation for the pump wave which is valid when the wavelength of the perturbations $(\sim k^{-1})$ is considered much smaller than the scalesize of the variation of the pump-field (k_0^{-1}), i.e., $k_0 \ll k$. We shall use the two-fluid equations in describing the electron - and ion - fluid dynamics,

$$\frac{\partial}{\partial t} N_\alpha + \nabla \cdot (N_\alpha \underline{V}_\alpha) = 0 \qquad (1)$$

$$N_\alpha M_\alpha \left(\frac{\partial}{\partial t} + \underline{V}_\alpha \cdot \nabla\right)\underline{V}_\alpha = - \nabla P_\alpha \pm e N_\alpha \left(\underline{E} + \frac{\underline{V}_\alpha \times \underline{B}_0}{c}\right) - \nu_\alpha M_\alpha N_\alpha \underline{V}_\alpha \qquad (2)$$

$$P_\alpha = N_\alpha T_\alpha \qquad (3)$$

$$\nabla \cdot \underline{E} = 4\pi e (N_i - N_e) \qquad (4)$$

We initially assume cold ions $(T_i = 0)$. Later, we will present results that include the ion-temperature effects $(T_i \neq 0)$. In Eq. (1)-(4), M, N, V, P, T denote the mass, number density, velocity, pressure, and temperature, respectively, of the species α; ν_α is the collision frequency of

species α with the neutrals, and e, c, $\underline{E}$, and $\underline{B}$ represent electric charge, velocity of light, electric field and magnetic field, respectively. Since we restrict this study to bottom-side altitudes we take $\nu_{ii} \lesssim \nu_{in}$ where ν_{ii} is the ion-ion collision frequency and ν_{in} the ion-neutral collision frequency. In equilibrium, we have

$$\nabla \cdot N_0(\underline{V}_\alpha + \underline{V}_{\alpha p}) = 0 \tag{5}$$

$$0 = \pm \frac{e}{m_\alpha}\left(\underline{E}_0 + \frac{\underline{V}_{\alpha 0} \times \underline{B}}{c}\right) - \nu_\alpha \underline{V}_{\alpha 0} - \nabla P_{\alpha 0}/m_\alpha N_\alpha \tag{6}$$

$$\frac{d\underline{V}_{\alpha p}}{dt} = \pm \frac{e}{m_\alpha}\left(\underline{E}_p + \frac{\underline{V}_{\alpha p} \times \underline{B}}{c}\right) - \nu_\alpha \underline{V}_{\alpha p} \tag{7}$$

where α = e,i, and $\underline{V}_0$ and $\underline{V}_p$ refer to drifts induced by the ambient and pump fields, respectively. Note that eq. (7) describes the approximate equilibrium oscillatory motion of plasma particles under the action of the RF electromagnetic field. Linearizing (1) - (4) for perturbations, $f_\alpha = f_{\alpha 0} + \delta f_\alpha$, and assuming $\delta f_\alpha \ll f_{\alpha 0}$, we obtain

$$\frac{\partial}{\partial t}\delta n_\alpha + (\underline{V}_{\alpha 0} + \underline{V}_{\alpha p}) \cdot \nabla \delta n_\alpha + \delta \underline{v}_\alpha \cdot \nabla N_0 + N_0 \nabla \cdot \delta \underline{v}_\alpha = 0 \tag{8}$$

$$\frac{\partial \delta \underline{v}_\alpha}{\partial t} + (\underline{V}_{\alpha 0} + \underline{V}_{\alpha p}) \cdot \nabla \delta \underline{v}_\alpha = \pm \frac{e}{m_\alpha}\left[\delta \underline{E} + \frac{\delta \underline{v}_\alpha \times \underline{B}}{c}\right] - \frac{\nabla \delta p_\alpha}{m_\alpha N_0} - \nu_\alpha \delta \underline{v}_\alpha \tag{9}$$

$$\nabla \cdot \delta \underline{E} = 4\pi e(\delta n_i - \delta n_e) \tag{10}$$

It is convenient to transform to an oscillating frame, defined by

$$\underline{r}'_j = \underline{r} - \underline{R}_j(t)$$

$$\frac{d\underline{R}_j(t)}{dt} = \underline{V}_{\alpha 0} \tag{11}$$

The plasma quantities in the oscillating frame are $\delta\tilde{f}_\alpha(\tilde{r}'_\alpha, t) = \delta f_\alpha(r_\alpha, t)$ where the prime denotes the oscillating frame quantities. Equations (8) - (9) are similar in the oscillating frame, with substitutions $(V_{\alpha 0} + V_{\alpha p}) \rightarrow V_{\alpha 0}$, $\delta n_\alpha \rightarrow \delta\tilde{n}_\alpha$, $\delta\underline{v}_\alpha \rightarrow \delta\tilde{\underline{v}}_\alpha$, $\delta\underline{E} \rightarrow \delta\tilde{\underline{E}}$ and $\underline{r} \rightarrow \tilde{\underline{r}}_\alpha$. Assuming a harmonic perturbation, $\exp\left[i(\underline{k} \cdot \tilde{\underline{r}}_\alpha - \omega t)\right]$ with $\underline{k} = (k_x x + k_y y + k_z z)$ and $\omega = \omega_r + i\gamma$, we may combine (8) and (9) and write

$$\delta\tilde{n}_e = \frac{ik\chi_e}{e}\,\delta\tilde{E}, \tag{12a}$$

$$\delta\tilde{n}_i = -\,i\,\frac{k\chi_i}{e}\,\delta\tilde{E} \tag{12b}$$

where

$$4\pi\chi_e = \frac{(\omega_{pe}^2/k^2)}{\left(\tilde{\omega}_e - \frac{v_e^2 k_z^2}{\hat{\omega}} + \hat{\omega}\,\frac{v_e^2 k_\perp^2}{\Omega_e^2 - \hat{\omega}^2}\right)}\left(-\frac{k_z^2}{\hat{\omega}} + \hat{\omega}\,\frac{k_\perp^2}{\Omega_e^2 - \hat{\omega}^2}\right) \tag{13}$$

and

$$4\pi\chi_i = -\,\frac{\omega_{pi}^2\left(1 + i\,\frac{\nu_i}{\omega}\right)}{\left[(\omega + i\nu_i)^2 - \Omega_i^2\right]} \tag{14}$$

and

$$\omega_{p\alpha}^2 = \frac{4\pi n_0 e^2}{m_\alpha},\ \hat{\omega} = \tilde{\omega}_e + i\nu_e,\ \tilde{\omega}_\alpha = \omega - \underline{k}\cdot\underline{V}_0,\ q_\alpha = \pm\, e,\ \Omega_\alpha = \frac{q_\alpha B_0}{m_\alpha c}$$

We have used $\nabla N_0 = 0$, $T_i = 0$ in deriving (13) - (14). One now transforms back to the laboratory frame and writes down the dispersion relation for the modes by using the Poisson's equation. This transformation has been discussed in Lee et al. [1972], and the dispersion relation, thus obtained, is

$$[1 + 4\pi(\chi_i + \chi_e)] = - J_1^2(\zeta)4\pi\ \chi_i(1 + 4\pi\ \chi_e)\left[\frac{1}{H_e(\omega_+)} + \frac{1}{H_e(\omega_-)}\right] \tag{15}$$

where $\omega_{\pm} = \omega \pm \omega_0$ and,

$$J_n(\zeta) = \frac{i^{-n}}{\pi} \int_0^{\pi} e^{i\zeta\cos\theta} \cos n\theta d\theta \tag{16}$$

and ζ is defined by $\underline{k} \cdot \underline{R} = \zeta \sin(\omega_0 t + \beta)$, and, $H_e = - \frac{1}{(4\pi\ \chi_e)}(1 + 4\pi\ \chi_e)$. Note that we have ignored the effect of the pump wave on ions and have used the approximation $\zeta << 1$ in deriving (15) which states that the electron excursion length in the pump field is smaller than the perturbation wavelength. In absence of the pump field, the left hand side of (15) leads to the dispersion relation for ion-cyclotron waves [Chaturvedi, 1976],

$$(\omega + i\nu_i)^2 - \Omega_i^2 - \left[c_s^2k^2 - i\ \frac{m_e}{m_i}\frac{k^2}{k_z^2}\ \nu_e(\omega - k_zV_0)\right]\left(1 + i\ \frac{\nu_i}{\omega}\right) = 0 \tag{17}$$

which describes a resistive ion-cyclotron instability for modes with real frequency,

$$\omega_r^2 = \Omega_i^2 + k^2c_s^2 \tag{18a}$$

and growth rate (18b)

$$\gamma \approx -\frac{1}{2}\frac{m_e}{m_i}\frac{k^2}{k_z^2}\nu_e\left(1-\frac{k_z V_0}{\omega_r}\right)-\nu_i$$

where $C_s^2 = T_e/m_i$. An application of this instability for the auroral ionosphere has recently been discussed by Satyanarayana et al. [1985]. Physically, the instability is related to the dissipative effect on electrons in their parallel motion which impedes the "instantaneous" redistribution of the electron fluid to a Boltzmann-like distribution in the wave potential. In the collisionless limit, the dissipation is due to the wave-particle (Landau) resonance [Drummond and Rosenbluth, 1962], while in the collisional case, it is caused by the electron collisions with ions (or neutrals) [Chaturvedi and Kaw, 1975]. When the electron drift velocity exceeds the parallel wave phase velocity, the electrostatic ion cyclotron (EIC) wave becomes unstable.

In the presence of the pump-wave, the dispersion relation (17) is modified to

$$\Big[(\omega+i\nu_i)^2-\Omega_i^2-\{k^2C_s^2+(m_e/m_i)(\hat{\omega}^2-(k_z^2/k^2)\Omega_e^2)^{-1}(\hat{\omega}\,\tilde{\omega}_e)(\Omega_e^2-\hat{\omega}^2)\}\left(1+i\frac{\nu_i}{\omega}\right)\Big]=A \tag{19}$$

which gives

$$\omega_r^2=\Omega_i^2+k^2C_s^2+A \tag{20}$$

and

$$\gamma = \frac{m_e}{2m_i}\frac{k^2}{k_z^2}\frac{\nu_e}{\bar{\Omega}_i}\left(k_z V_0 - \bar{\Omega}_i - \frac{A}{2\bar{\Omega}_i}\right) - \nu_i \tag{21}$$

where

$$A = 2J_1^2(\zeta)\left(\omega_{pe}^2\omega_{pi}^2\right)\frac{\left(\delta + \frac{\nu_e}{\omega_0}\beta\right)}{\left(\delta^2 + \beta^2\right)} \tag{22}$$

$$\bar{\Omega}_i^{\,2} = \Omega_i^2 + C_s^{\,2}k^2,$$

$$\delta = \omega_0^2 - \omega_{UH}^2,\quad \omega_{UH}^2 = \Omega_e^2 + \bar{\omega}_{pe}^{\,2} + \nu_e^2$$

$$\bar{\omega}_{pe}^{\,2} = \omega_{pe}^{\,2} + v_e^2k^2,\quad \beta = \nu_e\omega_0\left(2 - \frac{\bar{\omega}_{pe}^{\,2}}{\omega_0^2}\right)$$

and,

$$\begin{aligned}\zeta^2 = \frac{e^2}{m_e^2(\omega_0^2 - \Omega_e^2)^2}\Big\{&k_x^2E_{px}^{\,2} + k_y^2E_{py}^{\,2} + \frac{\Omega_e^2}{\omega_0^2}\left(k_y^2E_{px}^{\,2} + k_x^2E_{py}^{\,2}\right) + \\ &2E_{px}E_{py}\left[k_xk_y\cos\psi\left(1 - \frac{\Omega_e^2}{\omega_0^2}\right) - \frac{\Omega_e}{\omega_0}k_\perp^2\sin\psi\right] \\ &+ \frac{(\omega_0^2 - \Omega_e^2)}{\omega_0^2}k_zE_{pz}\left[k_xE_{px} - \frac{\Omega_e}{\omega_0}k_xE_{px}\sin\psi + k_yE_{py}\cos\psi\right]\Big\}\end{aligned} \tag{23}$$

Here, the pump wave is taken as [Lee et al., 1972]

$$\underline{E}_p = \frac{E_{px}}{-2i}\exp(-i\omega_0t)\hat{x} + \frac{E_{py}}{-2i}\exp(-i\omega_0t - i\psi)\hat{y} + \frac{E_{pz}}{-2i}\exp(-i\omega_0t)\hat{z} + c.c. \tag{24}$$

where, E_{pz}, is included as we are considering modes with $k_z \neq 0$. We have

used $\Omega_e/\nu_e > k/k_z$, $\omega_r > \gamma$, ν_{in}, and, $1 > A/\bar{\Omega}_i^2$, in deriving (20) - (21). We can rewrite the modified growth rate of the modes as

$$\gamma = \left[\frac{k^2}{2k_z^2}\frac{\nu_e}{\Omega_e}\left(k_z V_0 - \bar{\Omega}_i\right) - \nu_i\right] - \frac{k^2}{2k_z^2}\frac{\nu_e}{\Omega_e}\frac{(\zeta^2/16)}{\bar{\Omega}_i}\frac{(\omega_{pe}^2\omega_{pi}^2)\delta}{(\delta^2 + \beta^2)} = \gamma^L - \gamma_s \qquad (25)$$

where γ^L denotes the linear growth contribution in absence of the pump-field while γ_s represents the modification introduced by the pump. We have again used $\zeta \ll 1$ in going from (21) to (25). We see from inspection of (25) that the presence of the pump can be stabilizing (destabilizing) if $\delta > 0$ (< 0), or, when $\omega_0 > \omega_{UH}$ ($\omega_0 < \omega_{UH}$). We note that similar criteria were also obtained by earlier workers [Lee et al., 1972, Bujarbarua and Sen, 1978, Keskinen et al., 1983].

We can treat the finite ion temperature effects in a similar fashion. Since the ion-cyclotron instability has maximum growth rate in the ionosphere near $k_\perp\rho_i \sim 1$, [Satyanarayana et al., 1985; Kindel and Kennel, 1971] one needs to use the kinetic (collisionless Vlasov-Boltzmann) equation for ions [Dum and Dupree, 1970]. In this case, the modified dispersion relation becomes,

$$\omega = \Omega_i\left[1 + \Gamma_{1i}\tau\left\{\left(1 - i\frac{\nu_e\bar{\omega}_e}{k_z^2 v_e^2}\right) + 2J_1^2(\zeta)\frac{\omega_{pe}^4}{k^2 v_e^2}\frac{\left(\delta + \frac{\nu_e}{\omega_0}\beta\right)}{(\delta^2 + \beta^2)}\right\}\left\{1 - i\sqrt{\pi}\,\frac{\omega t}{\Omega_i}\,e^{-t^2}\right\}\right.$$
$$\left. - i(\nu_i/\Omega_i)\right] \qquad (26)$$

where,

$$\tau = \frac{T_e}{T_i};\quad t = \left(\frac{\omega - \Omega_i}{k_z v_i}\right);\quad \Gamma_n(\mu_\alpha) = I_n(\mu_\alpha)e^{-\mu_\alpha};\quad \mu_\alpha = \frac{k_\perp^2 v_\alpha^2}{\Omega_\alpha^2} \qquad (27)$$

In the absence of the pump wave, this expression yields the ion-cyclotron wave dispersion relation,

$$\omega = \Omega_i[1 + \Gamma_{1i}\tau\{1 - i\frac{\nu_e\bar{\omega}_e}{k_z^2 v_e^2} - i\sqrt{\pi}\frac{\omega t}{\Omega_i}\bar{e}^{t^2}\} - i(\nu_i/\Omega_i)] \tag{28}$$

which yields the expressions for the real frequency and the growth rate

$$\omega_r = \Omega_i[1 + \Gamma_{1i}\tau],$$

$$\gamma = -\Omega_i\Gamma_{1i}\tau\,[\frac{\nu_e\bar{\omega}_e}{k_z^2 v_e^2} + \sqrt{\pi}\frac{\omega_r}{k_z v_i}\Gamma_{1i}\bar{e}^{t^2}] - \nu_i - \nu_{ii}k_\perp^2\rho_i^2 \tag{29}$$

where the second term in (29) in the expression for γ results from the ion-Landau damping and we have added a contribution (last term) due to ion-viscous damping [Dum and Dupree, 1970] for completeness. The collisional ion-cyclotron instability described by (29) may have relevance for the short wavelength observations (such that $k_\perp\rho_i \sim 1$) of ion-cyclotron waves at low ionospheric altitudes [Bering, 1984; Satyanarayana et al., 1985].

The inclusion of pump wave effects in equation (28) leads to modification of (29) in the form given by

$$\omega_r = \Omega_i[1 + \Gamma_{1i}(\tau + \frac{A}{k^2 v_i^2})],$$

$$\gamma = \gamma_- - (\Gamma_{1i})^2\frac{\tau}{\mu_i}\frac{\nu_e}{k_z^2 v_e^2}A \tag{30}$$

where A and γ_- are given by (22) and (29) respectively. We see that the pump wave is stabilizing (destabilizing) for $\delta > 0$ (< 0), i.e.,

when $\omega_o > \omega_{UH}(\omega_o < \omega_{UH})$; as in case of fluid ions (eq. (25)). One can readily extend this analysis to the case of the kinetic EIC instability [Drummond and Rosenbluth, 1962]. However, in the ionosphere, the kinetic instability is likely to occur at higher altitudes [Kindel and Kennel, 1971] such as above the F peak; whereas, the modification experiments have access only to the lower collisional altitudes.

A rough estimate for the threshold amplitude of the pump-field required to stabilize or destabilize the collisional EIC instability, reveals that (using (30)),

$$\frac{cE_p^2}{3\pi} = \frac{\mu_i}{\Gamma_{1i}} \frac{B_0^2}{ck_\perp^2} \frac{\omega_0^2(\omega_o - \Omega_e)^2}{\Omega_e^2} \frac{k_z^2 v_e^2 \omega_0 \Omega_e}{\omega_{pe}^4} \left[\frac{\nu_e(k_z V_0 - \omega_r)}{k_z^2 v_e^2} - \pi^{1/2}\frac{\omega_r}{k_z v_i}\Gamma_{1i} e^{-t^2}\right.$$

$$\left. - (\Gamma_{1i}\tau\Omega_i)^{-1}(\nu_i + \nu_{ii}k_\perp^2\rho_i^2)\right] \qquad (31)$$

where t is given by (27) and we have considered a circularly-polarized O-mode, so $\psi = -\pi/2$ and $|E_{px}| = |E_{py}|$. For typical high-latitude F-region parameters [Satyanarayana et al., 1985], we have, $B_0 \sim 0.5$ G, $\nu_e/\Omega_e \sim 10^{-4}$, $\frac{k_z}{k_\perp} \sim 10^{-2}$, $k_\perp\rho_i \sim 1.5$, $\rho_i \sim 10^3$cm, $\omega_0 \sim \omega_{pe} \sim 3 \times 10^7 s^{-1}$, $T_e = T_i = 0.1$ eV, $\rho_e = 3$ cm, $V_0 \sim 2 \times 10^6$ cm s^{-1}, $\nu_i = 0.1$ sec^{-1}, $\nu_{ii} = 0.01$ sec^{-1}, giving that $c|E_p|^2/8\pi = 5 \times 10^{-4}$ W/m^2.

III. DISCUSSION

We have studied the effects of a high frequency electromagnetic pump wave on the evolution of ion cyclotron instabilities in a weakly ionized collisional plasma. We find that an electromagnetic pump wave oscillating

with the upper hybrid frequency can lead to the artificial production or control of ion cyclotron instabilities in a collisional plasma. The basic physical mechanism of this process can be expressed as follows. The electromagnetic pump wave with frequency ω_{UH} interacts with low frequency ion cyclotron modes ω and drives sidebands at $\omega \pm \omega_{UH}$. These sidebands can, in turn, couple to the pump fields and nonlinearly affect the ion cyclotron modes. This interaction is ponderomotive in nature. However, the partial pressure force (Fejer, 1979) can also play a role depending upon the $k_\parallel$ of the sidebands. Fejer [1979] has shown that the partial pressure force exceeds the ponderomotive force roughly when $\lambda_\parallel > 4\lambda_e$, where λ_e is the electron mean free path. For the collisional EIC, $(k_z/k_\perp) \sim 0.06$, $(k_\perp \rho_i) \sim 1.5$ and $\lambda_e \sim 1$ km. [Satyanarayana et al., 1985], which implies, $\lambda_\parallel < \lambda_e$. Thus, for the ion-cyclotron modes, the predominant pump-wave-induced parametric effects are likely to be of ponderomotive force-like in nature. For parameters typical of the high latitude ionosphere, we find that ion cyclotron modes can be stabilized or destabilized with an incident pump electric field on the order of 0.1 V/m. The polarization of the pump wave should be O mode. These power density levels could be accessible using the ionospheric heaters in Alaska (Wong et al., 1981) and Norway (Stubbe et al., 1981).

We have made several simplifying assumptions in the course of this paper. We have assumed the dipole approximation, i.e., taken the wavelength of the pump wave $\sim k_p^{-1}$ to be much larger than the wavelength of the ion cyclotron modes k^{-1}. Since $k_p^{-1} \sim 100$'s m and $k^{-1} \sim \rho_i \sim 10$ m, this assumption is valid. In addition, we have neglected pump electric field swelling near the reflection point (Ginzburg, 1964) and, as a result, our threshold pump electric fields should be considered as lower bounds.

Acknowledgments

This work was supported by the Office of Naval Research. We thank J. Huba for a critical reading of the manuscript and useful discussions.

References

Aarons, J.,	1973	J. Geophys. Res., 78, 7441.
Basu, S., S. Basu, E. MacKenzie, W.R. Coley, W.B. Hanson and C.S. Lin	1984	J. Geophys. Res, 89, 5554.
Bering, E.A.,	1984	J. Geophys. Res., 89, 1635.
Bujarbarua, S. and Sen, A.	1978	J. Atmos. Terr. Phys. 40, 615.
Burke, W.J.,	1981	Physics of Auroral Arc Formation, AGU, Washington, DC, p. 164.
Chaturvedi, P.K., and P.K. Kaw	1975	Plasma Physics, 17, 447.
Chaturvedi, P.K.	1976	J. Geophys. Res. 81, 6169.
Clark, D.H., and W.J. Raitt	1976	Planet. Space Sci., 24, 873.
Das, A.C. and J.A. Fejer	1979	J. Geophys. Res 84, 6701
Drummond, W.E., and M.N. Rosenbluth	1962	Phys. Fluids, 5, 1507.
DuBois, D.F., and M.V. Goldman	1965	Phys. Rev. Lett., 14, 544.
Dum, C.T. and T.H. Dupree	1970	Phys. Fluids, 13, 2064.
Dyson, P.L.,	1969	J. Geophys. Res., 74 6291.
Dyson, P.L., and J.D. Winningham	1974	J. Geophys. Res., 79, 5219.
Fejer, B.G., Reed, R.W., Farley, D.T., Swartz, W.E., and Kelley, M.C.	1984	J. Geophys. Res. 89, 187.

Fejer J.A. 1979 Rev. Geophys. Space Phys. 17, 135.

Fialer P.A. 1974 Radio Sci. 9, 923.

Fremouw, E.J., C.L. Rino, R.C. Livingston, and M.D. Cousins 1977 Geophys. Res. Lett., 4, 539.

Ginzburg V.L. 1964 The Propagation of Electromagnetic Waves in Plasma, Addison Wesley, Reading, Mass.

Greenwald, R.A., 1974 J. Geophys. Res., 79, 4807.

Hanuise, C., J.P. Villain and M. Crochet 1981 Geophys. Res. Lett., 8, 1083.

Hower, G.L., D.M. Ranz and C.L. Allison 1966 J. Geophys. Res., 71, 3215.

Kelley, M.C., K.D. Baker, M.J. Baron, C.L. Rino 1980 Radio Sci., 15, 491.
and J.C. Ulwick 1983 Radio Sci., 18, 1077.

Keskinen, M.J., and S.L. Ossakow 1983 J. Geophys. Res. 88, 7239.

Keskinen, M.J., Chaturvedi, P.K. and Ossakow, S.L. 1971 J. Geophys. Res., 76, 3055.

Kindel, J.M., and C.F. Kennel 1972 J. Geophys. Res. 77, 4197.

Lee K., Kaw, P.K., and Kennel, C.F. 1968 J. Phys. Soc. Jpn., 24, 916.

Nishikawa, K. 1976 J. Geophys. Res., 81, 4013.

Ogawa, T., H. Mori, and S. Miyazaki

Olesen, J.K., F. Primdahl, F. Spangslev, E. Ungstrup A. Bahnsen, U. Fahleson, C. -G. Fälthammar, and A. Pedersen	1976	Geophys. Res. Lett., 3, 399.
Ossakow, S.L., and P.K. Chaturvedi	1979	Geophys. Res. Lett., 6, 332.
Perkins, F.W., and P.K. Kaw	1971	J. Geophys. Res., 76, 282.
Perkins, F.W., C. Oberman, and E.J. Valeo	1974	J. Geophys. Res., 79 1478.
Phelps, A.D.R.and R.C. Sagalyn	1976	J. Geophys. Res., 81, 515.
Sagalyn, R.C., M. Smiddy, and M. Ahmed	1974	J. Geophys. Res., 79, 4252.
Satynanarayana, P., P.K. Chaturvedi, M.J. Keskinen, J.D. Huba and S.L. Ossakow	1985	J. Geophys. (in press).
Silin, V.P,	1965	Sov. Phys. JETP, 21, 1127.
Stenflo, L.	1983	Radio Sci. 18, 1379.
Stubbe, P., Kopka, H. and Dowden, R.L.	1981	J. Geophys. Res. 86, 9073.
Thidé, B., Kopka, H. and Stubbe, P.	1982	Phys. Rev. Lett. 49, 1561.
Utlaut, W.F.,	1970	J. Geophys. Res., 75, 6402.
Vaskov, V.V., and A.V. Gurevich	1977	Sov. Phys. JETP, 46, 487.
Vickrey, J.F., C.L. Rino T.A. Potemra	1980	Geophys. Res. Lett., 7, 789.

Weaver, P.F.	1965	J. Geophys. Res., 70, 5425.
Wong, A.Y., Roederer, J. Hunsucker, R., Dimonte, G., Viezbicke, P., Gregorio, J., and Santoru, J.	1981	Effects of the Ionosphere on Radio-wave Systems, ed. J. Goodman, U.S. Government Printing Office, Washington, D.C.

IONOSPHERIC MODELING DISTRIBUTION LIST
(UNCLASSIFIED ONLY)

PLEASE DISTRIBUTE ONE COPY TO EACH OF THE FOLLOWING PEOPLE (UNLESS OTHERWISE NOTED)

NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375
DR. S. OSSAKOW - Code 4700 (26 Copies)
Code 4701
Code 4780 (50 copies)
Code 4100
DR. H. GURSKY - CODE 4100
DR. J. GOODMAN - CODE 4180
DR. P. RODRUQUEZ - CODE 4706
CODE 2628 - 22 Copies
CODE 1220 - 1 Copy

A.F. GEOPHYSICS LABORATORY
L.G. HANSCOM FIELD
BEDFORD, MA 01731
DR. T. ELKINS
DR. W. SWIDER
MRS. R. SAGALYN
DR. J.M. FORBES
DR. T.J. KENESHEA
DR. W. BURKE
DR. H. CARLSON
DR. J. JASPERSE
Dr. F.J. RICH
DR. N. MAYNARD

BOSTON UNIVERSITY
DEPARTMENT OF ASTRONOMY
BOSTON, MA 02215
DR. J. AARONS

CORNELL UNIVERSITY
ITHACA, NY 14850
DR. W.E. SWARTZ
DR. R. SUDAN
DR. D. FARLEY
DR. M. KELLEY

HARVARD UNIVERSITY
HARVARD SQUARE
CAMBRIDGE, MA 02138
DR. M.B. McELROY
DR. R. LINDZEN

INSTITUTE FOR DEFENSE ANALYSIS
400 ARMY/NAVY DRIVE
ARLINGTON, VA 22202
DR. E. BAUER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PLASMA FUSION CENTER
LIBRARY, NW16-262
CAMBRIDGE, MA 02139

NASA
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD 20771
DR. R.F. BENSON
DR. K. MAEDA
Dr. S. CURTIS
Dr. M. DUBIN

COMMANDER
NAVAL AIR SYSTEMS COMMAND
DEPARTMENT OF THE NAVY
WASHINGTON, D.C. 20360
DR. T. CZUBA

COMMANDER
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO. CA 92152
MR. R. ROSE - CODE 5321

NOAA
DIRECTOR OF SPACE AND ENVIRONMENTAL LABORATORY
BOULDER, CO 80302
DR. A. GLENN JEAN
DR. G.W. ADAMS
DR. D.N. ANDERSON
DR. K. DAVIES
DR. R. F. DONNELLY

OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217
DR. G. JOINER

LABORATORY FOR PLASMA AND FUSION ENERGIES STUDIES
UNIVERSITY OF MARYLAND
COLLEGE PARK, MD 20742
JHAN VARYAN HELLMAN, REFERENCE LIBRARIAN

PENNSYLVANIA STATE UNIVERSITY
UNIVERSITY PARK, PA 16802
DR. J.S. NISBET
DR. P.R. ROHRBAUGH
DR. L.A. CARPENTER
DR. M. LEE
DR. R. DIVANY
DR. P. BENNETT
DR. F. KLEVANS

PRINCETON UNIVERSITY
PLASMA PHYSICS LABORATORY
PRINCETON, NJ 08540
DR. F. PERKINS

SCIENCE APPLICATIONS, INC.
1150 PROSPECT PLAZA
LA JOLLA, CA 92037
DR. D.A. HAMLIN
DR. L. LINSON
DR. E. FRIEMAN

STANFORD UNIVERSITY
STANFORD, CA 94305
DR. P.M. BANKS

U.S. ARMY ABERDEEN RESEARCH
AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
ABERDEEN, MD
DR. J. HEIMERL

GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
FAIRBANKS, AK 99701
DR. L.C. LEE

UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
J-10, MS-664
LOS ALAMOS, NM 87545
DR. M. PONGRATZ
DR. D. SIMONS
DR. G. BARASCH
DR. L. DUNCAN
DR. P. BERNHARDT
DR. S.P. GARY

UNIVERSITY OF ILLINOIS
DEPT. OF ELECTRICAL ENGINEERING
1406 W. GREEN STREET
URBANA, IL 61801
DR. ERHAN KUDEKI

UNIVERSITY OF CALIFORNIA,
LOS ANGELES
405 HILLGARD AVENUE
LOS ANGELES, CA 90024
DR. F.V. CORONITI
DR. C. KENNEL
DR. A.Y. WONG

UNIVERSITY OF MARYLAND
COLLEGE PARK, MD 20740
DR. K. PAPADOPOULOS
DR. E. OTT

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
DR. R. GREENWALD
DR. C. MENG

UNIVERSITY OF PITTSBURGH
PITTSBURGH, PA 15213
DR. N. ZABUSKY
DR. M. BIONDI
DR. E. OVERMAN

UNIVERSITY OF TEXAS
AT DALLAS
CENTER FOR SPACE SCIENCES
P.O. BOX 688
RICHARDSON, TEXAS 75080
DR. R. HEELIS
DR. W. HANSON
DR. J.P. McCLURE

UTAH STATE UNIVERSITY
4TH AND 8TH STREETS
LOGAN, UTAH 84322
DR. R. HARRIS
DR. K. BAKER
DR. R. SCHUNK
DR. J. ST.-MAURICE

PHYSICAL RESEARCH LABORATORY
PLASMA PHYSICS PROGRAMME
AHMEDABAD 380 009
INDIA
P.J. PATHAK, LIBRARIAN

Director of Research
U.S. Naval Academy
Annapolis, MD 21402 (2 copies)

END

FILMED

2-86

DTIC